Analysis of High Spatial, Temporal, and Directional Resolution Recordings of Biological Sounds in the Southern California Bight

Gerald L. D'Spain
Marine Physical Laboratory
Scripps Institution of Oceanography
291 Rosecrans Street
San Diego, CA 92106
phone: 858-534-5517 fax: 858-534-5255 email: gdspain@ucsd.edu

Award Number: N00014-12-1-0272
http://www-mpl.ucsd.edu

LONG-TERM GOALS

The long-term goals of this research effort are to detect, localize, and characterize the underwater biological sounds in the Southern California Bight, for the benefit of Navy environmental compliance. The particular focus in this program is on the biological sounds at low to mid frequencies - 5 to 1200 Hz - recorded by an advanced prototype Navy system deployed off the southern California coast in 1999. The efforts in this program also support the Ph.D. research of graduate students in marine bioacoustics and ocean acoustics at the Scripps Institution of Oceanography.

OBJECTIVES

The objective of this project is to conduct a set of biologically-focused research efforts using a high quality, high resolution ocean acoustic data set collected in 1999 off the Southern California coast. This data set was acquired in the Multi-Node Test/Fleet Evaluation Test (MNT/FET) by SPAWAR's Advanced Deployable System (ADS) program. The data analysis efforts support the thesis research by graduate students at the Scripps Institution of Oceanography (SIO), studying a) the potential impact of man-made sound on the calling behavior of transiting humpback whales in the Southern California Bight, b) the use of passive underwater acoustic techniques for improved habitat assessment in biologically sensitive areas and improved ecosystem modeling, and c) the application of the physics of excitable media to numerical modeling of biological choruses and extension to collective biological behavior. The analysis results characterize the low frequency underwater sonic environment in an area of operational (training) interest to the Navy, using a prototype Navy system.

APPROACH

In 1999, the Advanced Deployable System (ADS) program, part of SPAWAR's Integrated Undersea Surveillance System (IUSS), conducted a large exercise off the Southern California coast. This exercise involved the deployment of 16 horizontal hydrophone line arrays on the ocean bottom. The geometry of the array deployment is shown in Fig. 1. The outputs from these arrays were fiber-optic cabled to shore and recorded continuously for a period of a few months (not all arrays were deployed for all time periods). The ADS program was cancelled in 2004. Subsequently, responsibility for the

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2012	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Analysis of High Spatial, Temporal, and Directional Resolution Recordings of Biological Sounds in the Southern California Bight	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Marine Physical Laboratory Scripps Institution of Oceanography 291 Rosecrans Street San Diego, CA 92106**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**7**	

program was assumed by PMS-485, from which we received formal permission to obtain a copy of all unclassified array data recorded during this exercise. The complete data set is archived at the Applied Research Labs, University of Texas at Austin (ARL/UT), managed by Pete McCarty and Rich Gramann. While ARL/UT was in the process of transcribing their data archive onto newer recording media, they also provided us with a copy of the unclassified portion of this data set.

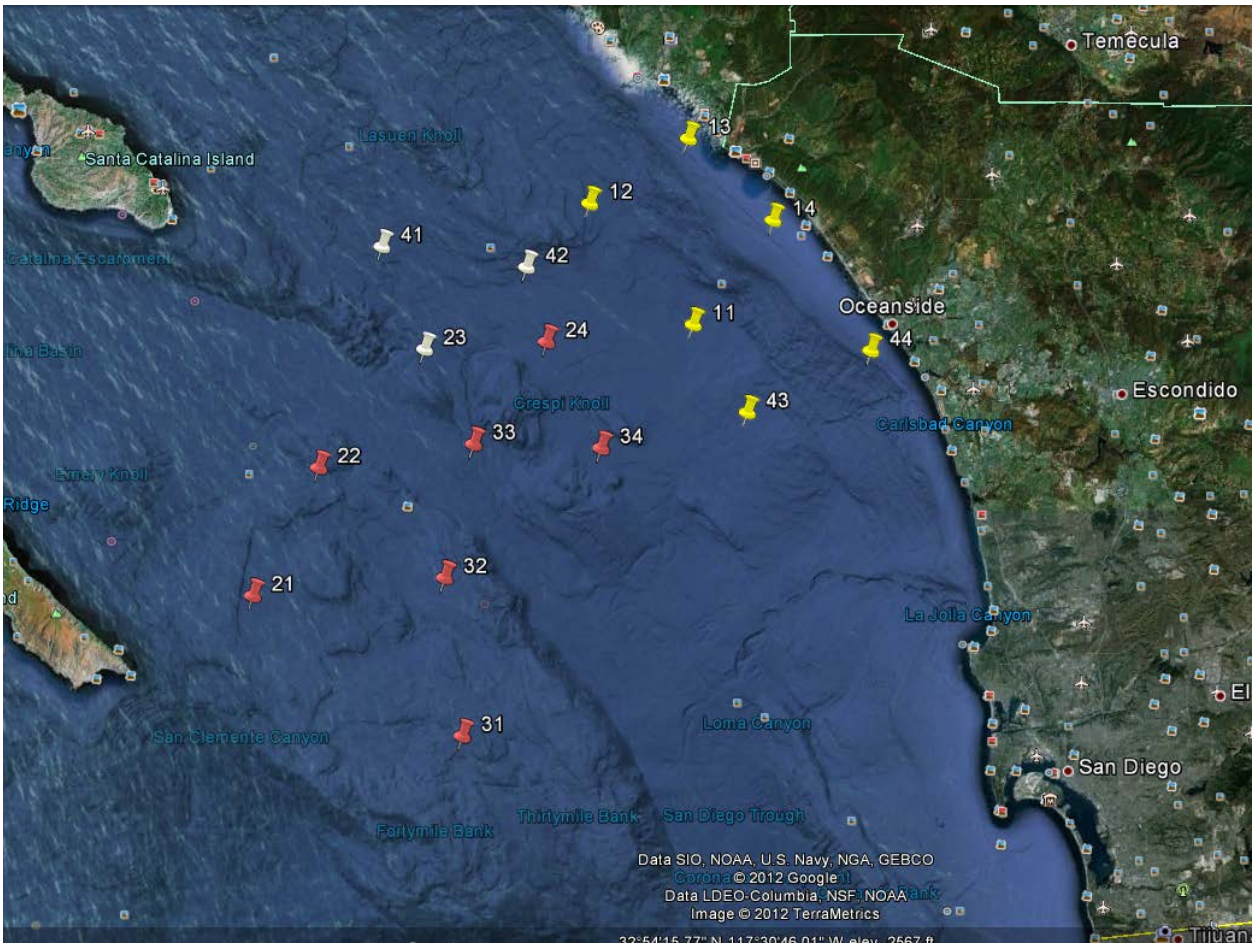

Figure 1. The locations of the 16 hydrophone arrays deployed during the ADS program's MNT/FET exercise in 1999 off the southern California coast are marked by colored push-pins on this Google Earth map. To the west of the array deployment area is Santa Catalina Island (northwest) and San Clemente Island (southwest). The array number is listed next to each corresponding push-pin location. The data from the near-coastal arrays marked by yellow push-pins were recorded on one time base, whereas the red-colored arrays were recorded on a second time base. The data from those arrays marked by white push-pins are classified over the full period of the exercise.

One Ph.D. graduate student working with the MNT/FET data is in his fifth year in the Applied Ocean Science curricular group at SIO. He is a recipient of a Department of Defense SMART fellowship (http://smart.asee.org/). The topic of his Ph.D. thesis is "The potential impact of man-made sounds on the calling behavior of transiting humpback whales in the Southern California Bight". The main scientific hypothesis to be tested in this research is that the evolution of unit structure and song characteristics in the population of transiting humpback whales in the Southern California Bight is

correlated, at least to some extent, with properties of the environment, with particular focus on those properties created by human activities. As part of this research, a detector based on a power-law processor that is approximately optimal for transient signals (Helble et al., 2012) was developed. This algorithm presently is being used to scan the MNT/FET for biologically-created transient signals.

A second graduate student whose research uses the MNT/FET data set comes from the Center for Marine Biodiversity and Conservation (CMBC) at SIO. This research thrust involves the integration of passive ocean acoustic measurements with standard methods to improve habitat assessments and ecological monitoring, including ecosystem modeling, and the use of this improved understanding to inform policy makers and resource managers. Presently, the research is involved in examining the relationships between archived oceanographic data, including those from the California Coastal Ocean Fisheries Investigation (CalCOFI) surveys, and the temporal, spatial, and directional properties of the underwater sound field from the MNT/FET data set. The overall scientific hypothesis being tested in this thesis research is that certain properties of passive acoustic recordings provide unique and useful information on the condition of marine habitats.

A third graduate student using the MNT/FET data is further developing numerical models of the chorusing behavior of fish and invertebrates. An initial model was developed to predict the unusual spatiotemporal patterns of a biological chorus observed off the Southern California coast in experiments conducted in the mid 1990s. This chorus also is present in the MNT/FET data (re Fig. 4). With changes in the input parameter settings, the model predicts an evolution from a continuous high-level chorus, as is often observed just after sunset, to one where the chorus amplitude cycles in time, as seen in the data from the mid 1990s (D'Spain et al., 1997). The sounds are hypothesized to be generated by croakers, members of the Sciaenidae family, and likely are from two species, queenfish and white croaker (D'Spain et al., 1997). The main goal of the present effort is to relate the model parameters to characteristics of the environment and the fishes themselves. An overall scientific hypothesis to be tested is that the properties of biological choruses, characterized by the parameter values in model fits to the data, provide insight into population-level structure and dynamics and trophic interactions of important food sources for certain marine mammal species

The approach in this project has been to a) convert the MNT/FET data into a binary format useable with custom MPL/SIO processing software and with Matlab, b) quality-check the data, c) create spectrograms of the data from a single element of selected sub-arrays to provide a pictorial history of the acoustic field properties during the exercise, d) locate periods of time likely to contain biological sounds using spectrograms and the GPL algorithm, e) beamform the array data containing marine biological sounds so that the graduate students and other researchers do not need access to the sensitive information on array design, and f) place the beamforming results containing biological sounds into a geographic information system (GIS) context (as in Batchelor and D'Spain, 2005).

The work in this project is leveraged with other ongoing programs, listed in Related Projects below.

WORK COMPLETED

All MNT/FET data received to date (over 2 TB) has been converted to a binary format which can be read by Matlab. This effort included writing custom software to convert the MNT/FET data from the CASDE format to a more general binary format, and to a binary format compatible with our in-house software packages. All data have been quality-checked and parsed into binary files for each of the 3

sub-arrays (low frequency, mid frequency, and high frequency) contained in each array. Selected portions of the data have been converted to our in-house binary format; the effort to convert the entire data set is ongoing.

Spectrograms have been created for one element of each of the three sub-arrays in an array, for over a third of the complete data recording period. This effort is ongoing. All grams have been examined to identify periods with biological sounds and other interesting transients for further analysis.

Ancillary and oceanographic data for the temporal and spatial attributes of the MNT/FET data set have been gathered and placed into a Geographic Information System (GIS) for use in habitat modeling and spatial analysis. The data are in a format compatible with Matlab, with ESRI ArcGIS, and with other data analysis software packages. The types of data assimilated to date include: bathymetry (from several sources), offshore landforms, marine protected area boundaries, species distribution for several of the fishes, temperature and salinity, and numerous types of satellite-based data, as well as locations of the MNT/FET arrays and HARP data recording packages.

RESULTS

The single-element spectrograms created to date shows numerous recordings of biological transients with excellent signal-to-noise ratio. In addition to these short-duration transient sounds, the low frequency chorus with cycling amplitude, observed in data from the mid 1990s, also is present. A few example spectrograms from the MNT/FET data are given below.

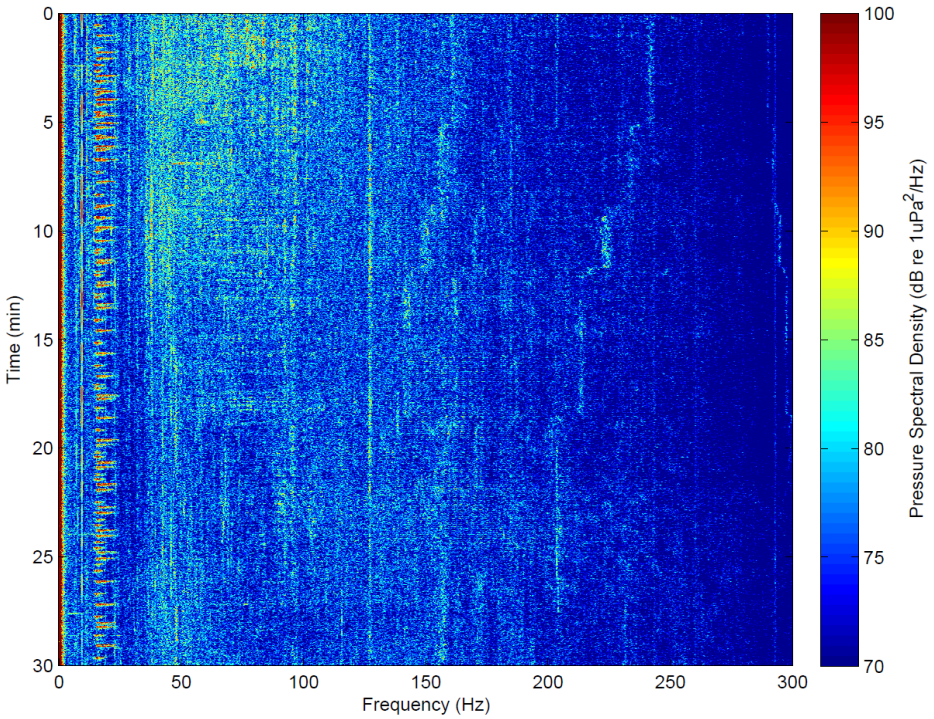

Figure 2. A spectrogram from Array 33 (located in the approximate center of the cluster of arrays in Fig. 1), from 0 to 300 Hz (horizontal axis) over a 30-minute period (time increasing from top to bottom on the vertical axis) contains a pattern of low-frequency transient sounds around 20 Hz due to a fin whale calling bout.

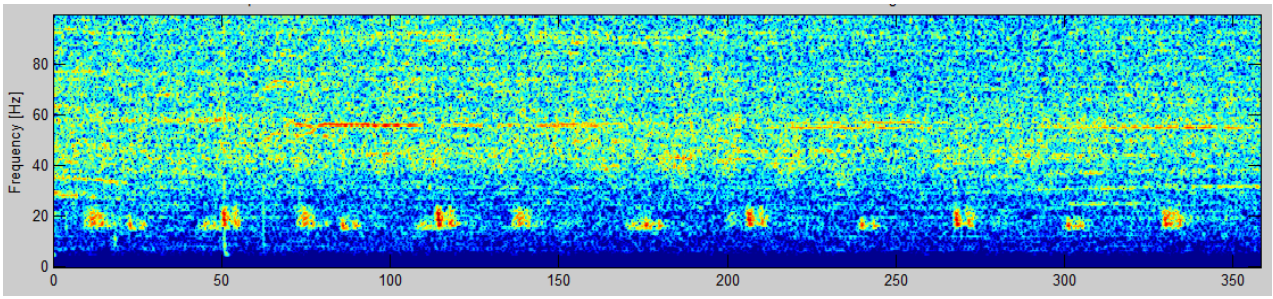

Figure 3. A spectrogram covering a 6-minute time period (time increasing left to right on the horizontal axis) after band-pass filtering from 5 to 100 Hz (vertical axis is from 0 to 100 Hz) provides a more detailed view these fin whale calls near 20 Hz. These fin whale sounds are ubiquitous throughout the MNT/FET data set, varying with respect to frequency content and temporal pattern.

The 5-min spectrogram on the right-hand side of Fig. 4 contains the nighttime fish chorus that creates received levels that cycle in amplitude. This amplitude cycling, most easily seen in the 500-600 Hz band at the far right of the plot, has a period of about 15 sec. The left-hand spectrogram in Fig. 4, recorded on the same day in the month of May but during daylight hours, is presented for comparison. It does not show any amplitude cycling. In addition to this periodic variability in amplitude, the overall received levels in the 300-500 Hz band are significantly higher at night than during the day, evident in the right-hand gram as a diffuse yellowish column. A transient of potential biological origin occurs in the left-hand gram at the 3.5-min mark just below 100 Hz. Analyses are underway on the directionality of these sounds using data-adaptive beamforming methods. Future analyses will include the spatial dependence, and temporal variability over the full duration of the MNT/FET exercise, of the occurrence of the nighttime fish chorus.

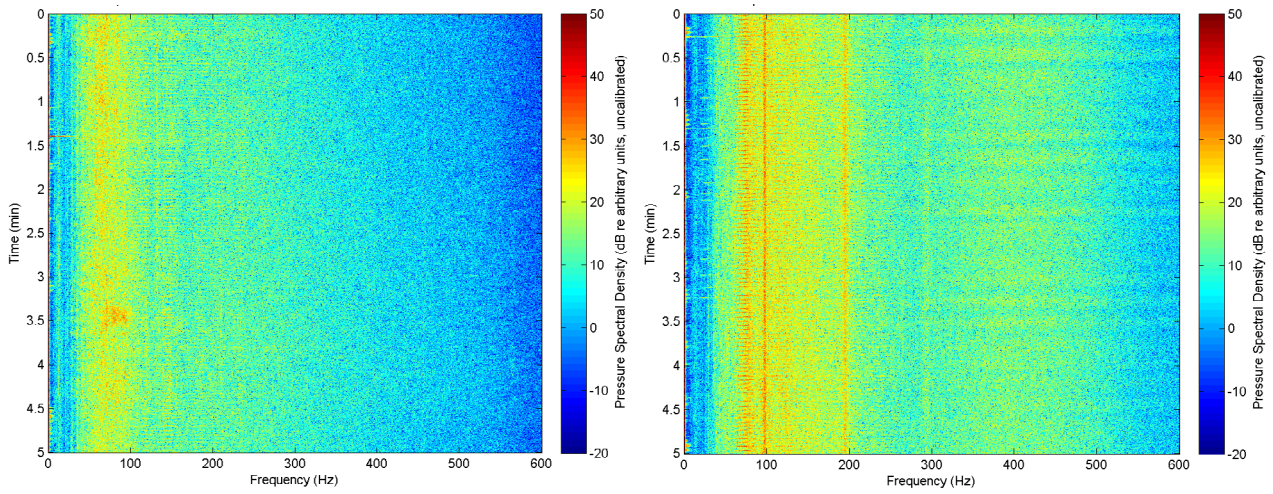

Figure 4. Two spectrograms each covering a 5-minute time period (time increasing downward on the vertical axis) over the 600 Hz frequency band (horizontal axis) illustrate the cycling-in-amplitude fish chorus. The data for both spectrograms were recorded by the same element of array 13 (the northern-most array close to shore in Fig. 1) on the same day in May, 1999. Both plots have the same color scale for the spectral density levels. Whereas the left-hand spectrogram was recorded during the daytime, the right-hand gram was recorded at night.

IMPACT/APPLICATIONS

Each of these scientific studies with the MNT/FET data set will contribute to a greater understanding of the ecosystem of the Southern California Bight, a region containing both a high density of marine mammals and a high level of U.S. Navy activity. The study on the question of the potential impact of Navy activities, and human activities as a whole, on humpback whale populations in the region is particularly relevant. A natural outgrowth of these studies will be a detailed characterization of the low frequency underwater sonic environment in and near the SOCAL and Camp Pendleton Navy Range Complexes off the Southern California coast, using data from a prototype Navy system. Finally, by supporting the research efforts of graduate students in the field of marine bioacoustics and ocean acoustics, this project will help provide the Navy with the future generation of highly trained ocean acousticians and bioacousticians aware of both Navy needs and environmental issues.

RELATED PROJECTS

The efforts in this project have been heavily leveraged with other programs. The Advanced Distributed Systems program collected the high quality, high spatial, temporal, and directional resolution MNT/FET data set. The data archival efforts by ARL/UT provided the opportunity to obtain a second copy of the data tapes. Both the Department of Defense SMART fellowship and other fellowship programs at CMBC and SIO are covering the graduate student costs. Algorithms from the Glider-Based Passive Acoustic Monitoring Techniques in the Southern California Region, Code 322-MBB, with John Hildebrand and Gerald D'Spain as co-PIs, have been, and are being, used to automatically scan the data for marine mammal calls and other biological sounds. Finally, the analyses also have used data from John Hildebrand's HARP-based passive acoustic monitoring program in the Southern California Bight, sponsored by the Navy's environmental activity, and from the CalCOFI program at the Scripps Institution of Oceanography.

REFERENCES

Batchelor, H. H. and G. L. D'Spain (2005). "Passively recorded acoustic data as a component of marine GIS," 25th ESRI Conference, San Diego, 28 July, 7 pgs.

CalCOFI Reports (2000). Vol. 41, January 1 – December 31, 1999, La Jolla, CA.

D'Spain, G. L., L. P. Berger, W. A. Kuperman, and W. S. Hodgkiss (1997). "Summer night sounds by fish in shallow water," In: *The Proceedings of the Shallow Water Acoustics Conference*, Beijing, China, pp. 379-384.

D'Spain, G. L. and H. H. Batchelor (2006). "Observations of biological choruses in the Southern California Bight: A chorus at midfrequencies," J. Acoust. Soc. Am. 120 (4), pp. 1942-1955.

D'Spain, G. L., H. H. Batchelor, and C. Berchok (2006). "Observation and modeling of a spatiotemporal pattern in fish chorusing," J. Acous. Soc. Am. 119 (5), p. 3211.

D'Spain, G. L., H. H. Batchelor, and C. Berchok (2008). "Passive acoustic mapping of marine biological choruses," J. Acoust. Soc. Am. 123 (5), pt. 2, p. 1922.

Helble, T. A., G. Ierley, G. L. D'Spain, M. A. Roche, and J. A. Hildebrand (2012). "A generalized power-law detection algorithm for humpback whale vocalizations," J. Acoust. Soc. Am. 131(4), pp. 2682-2699.

Lombard, E. (1911). "Le signe de l'élévation de la voix," Annales des Maladies de L'Oreille et du Larynx 37 (2), pp. 101–109.

Winfree, A. T. (2000). *The Geometry of Biological Time* (Springer, Berlin, 777 pgs.

PUBLICATIONS

Bezanon, L., G. L. D'Spain, H. H. Batchelor, T. A. Helble, et al. (2013). "The high resolution spatiotemporal pattern of an unusual nighttime fish chorus off the Southern California coast: Observations," J. Acoust. Soc. Am., in prep.

Bezanon, L., G. L. D'Spain, and T. A. Helble (2013). "The high resolution spatiotemporal pattern of an unusual nighttime fish chorus off the southern California coast: Numerical modeling," J. Acoust. Soc. Am., in prep.

D'Spain, G. L., T. A. Helble, H. H. Batchelor, et al. (2013). "(Near) optimal transient detection and localization with application to passive acoustic marine mammal monitoring," J. Acous. Soc. Am., in prep.

Presentations

Batchelor, H. H., G. L. D'Spain, and T. A. Helble (2013). "Spatial analysis of biological chorusing in the Southern California Bight," ESRI User Conference, San Diego, July, 2013.

D'Spain, G. L., H. H. Batchelor, T. A. Helble, et al. (2013). "Analysis of the biological sounds simultaneously recorded by multiple bottom hydrophone arrays in the Southern California Bight," to be presented at the Acoustical Society of America meeting, May, 2013.

TBD (2013). "Using passive acoustics for habitat model inputs: A case study from a high temporal/ spatial/directional resolution data set in the Southern California Bight," to be presented at IEEE Oceans 13, San Diego, September, 2013.